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Three components of our research program are described. The first is a completed study focused on induced and intrinsic periodicities in central and parietal-occipital EEG activity as measured by band-pass analysis of selected frequency bands. Alternating periods of visual-motor performance and rest in a video flight simulation task provided evidence for reciprocal changes in specific EEG frequency components both in relation to performance vs nonperformance and across trials. These data also disclosed the presence of a 75-90 min. periodicity in band-pass densities which could be detected only during nonperformance epochs. The second study sought a more comprehensive evaluation of the relationship between these EEG frequency-topography characteristics and visual-motor performance in a more sophisticated flight simulation task. Power spectral analysis of the EEG was combined with a multi-component quanitative analysis of performance. The evaluation of these data is still underway but preliminary findings indicate that EEG characteristics may predict performance and quantitatively label fatigue. The third study examined the feasibility and technical requirements of (cont.)

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obtaining viable EEG data in high-performance, military aircraft. In collaboration with the Flight-Test Wing at Edwards AFB, data were collected from passengers in T-38 aircraft during routine flight operations. A unique helmet was developed for the rapid and effective attachment of appropriate EEG electrodes which led to the acquisition of high quality EEG data. Preliminary evaluation of the dimension of rest-vigilance and G force-induced stress suggests that important EEG frequency-topography characteristics identified in our laboratory studies may also serve to track cognitive functions during actual flight.

A. Research Objectives:

The objectives addressed during this phase of our work may be summarized as follows:

1) Complete initial study of sensorimotor and visual cortical EEG correlates of performance in an extended flight simulation task using band-pass analysis. Focus on intrinsic and imposed biological periodicities in these data.

2) Initiate second, more comprehensive study to provide greater resolution of EEG-performance correlates using power-spectral analysis. Focus on problems of situational confusion and fatigue. and

3) Establish program at Edwards Air Force Base for in-flight testing of EEG recording techniques. Collect data for evaluation of EEG characteristics in relation to the dimensions of vigilance and G-induced changes in consciousness.

B. Status of Research:

1. Periodicities in EEG frequency-topography characteristics during an extended, standardized flight simulation task.

Introduction

The functions of the mammalian central nervous system are known to be

conditioned by a variety of both intrinsic and imposed biological periodicities. The most obvious of these is the 24 hour, or circadian, cycle related to the alternation of light and dark periods on this planet and resulting in a universal pattern of wakefulness and sleep among higher species. In addition to a circadian cycle, there are also known to be ultradian periodicities, or cycles whose duration is less than 24 hours. Of great interest in this regard is the so-called "basic rest-activity cycle," or BRAC, which is thought to reflect a primitive modulation of brain function mediated by structures in the mammalian brain stem (Kleitman, 1963; Sterman, 1972). A number of studies have suggested that the BRAC, among biological cycles, can have an important modulatory influuence upon task performance (Othmer et al, 1969; Kripke, 1974; Sterman et al, 1972).

In this study, we attempted to examine that conclusion within the context of a simulated flight task, focusing on the EEG and its relationship to task requirements and performance. In the area of aircraft operation, as in most human endeavors, goal-directed activities are conditioned to a variety of complex factors. The most systematic of these are established by the work schedule. Thus, while man functions within differing task requirements, he is, nevertheless, most often directed by a work schedule which demands performance within a specified time frame. These schedules themselves impose important ultradian influences on human physiology which, in turn, must interact with intrinsic biological modulation. Ultimately, any effort to examine or utilize the concept of a BRAC within the realm of normal, complex human behavior must consider this interaction.

Methods

Eight adult male subjects, ranging in age from 30 to 48 years, were employed in this study. Each subject was monitored polygraphically during 6 hours of alternating performance and nonperformance in a mock-up of an aircraft cockpit. Performance consisted of achieving a series of assigned flight paths through manipulation of orientation and velocity controls in a simulated F-16 video flight scenario. Subjects were instructed to complete the assigned course change as quickly as possible and to cease "flying" activity until the next adjustment was ordered. Instructions were delivered through a radio headset from a pre-recorded tape, and both timing of performance and compliance with instructions were carefully monitored. The resulting sequence consisted of 18 periods lasting approximately 5 minutes each of task execution followed by 10 minute periods of verified nontask activity. During nonperformance periods, activity varied from quiet resting with eyes open or closed to reading of magazines or textbook materials. A 15 minute "break" was provided at 45-minute intervals to provide for stretching, eating or toilet activities. During these periods the monitoring cable was disconnected from a master input plug to allow egress from the recording situation without removal of electrodes.

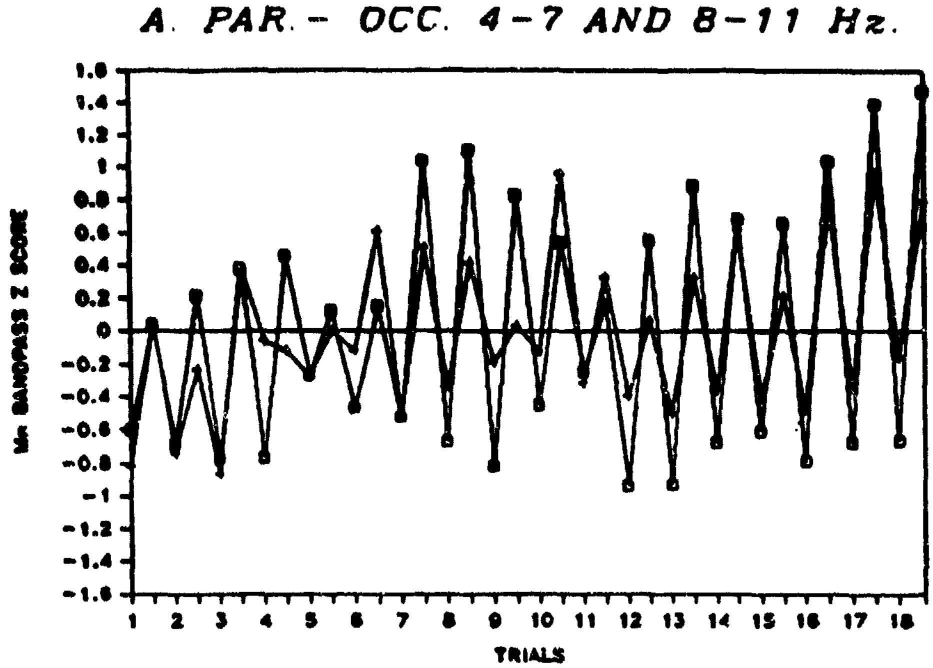
Monitored parameters included selected EEG leads, a chin (digastric muscle) EMG, and end-expired CO_2 percentage in respiratory gas. The present discussion will be limited to a review of EEG findings only. Two bipolar EEG placements were standard, and included central cortex (C_1C_5) and parietal-occipital cortex (P_3O_1) leads, according to the International 10-20 System. These leads, together with an ear-clip ground electrode, were fed to a Grass

polygraph and a bandpass frequency analyzer which automatically registered activity in three selected frequency bands (4-7, 8-11 and 12-15 Hz) from each cortical recording site every 15 seconds. From these data, mean values were determined for each performance and nonperformance epoch of the entire 18-trial sequence. In order to combine data from subjects with differing EEG baseline voltages, bandpass values from each subject were converted to standard Z-scores, with reference to the grand mean of all performance and nonperformance epochs.

Because of the nature of the commerical software used for this video flight task, performance measures were limited. Accordingly, these consisted of only two quantifiable tasks; one was recall of a seven digit number given at the beginning of each trial and tested at the end, and the second was the time required to complete the instructed course adjustment as reported by the subject. Both of these measures were equated in difficulty across the 18 trials. Standard scores were derived also for these measures in order to compare across subjects.

Results

Analysis of these data showed clearly that the sequence of performance and nonperformance periods across the 18 trials of this design imposed a significant ultradian periodicity on all of the frequency bands studied (Fig. 1). At the parietal-occipital cortex recording site, this periodicity was clearest in the 4-7 Hz band, with performance attenuating this frequency and nonperformance associated with enhancement. Conversely, at the central cortical recording



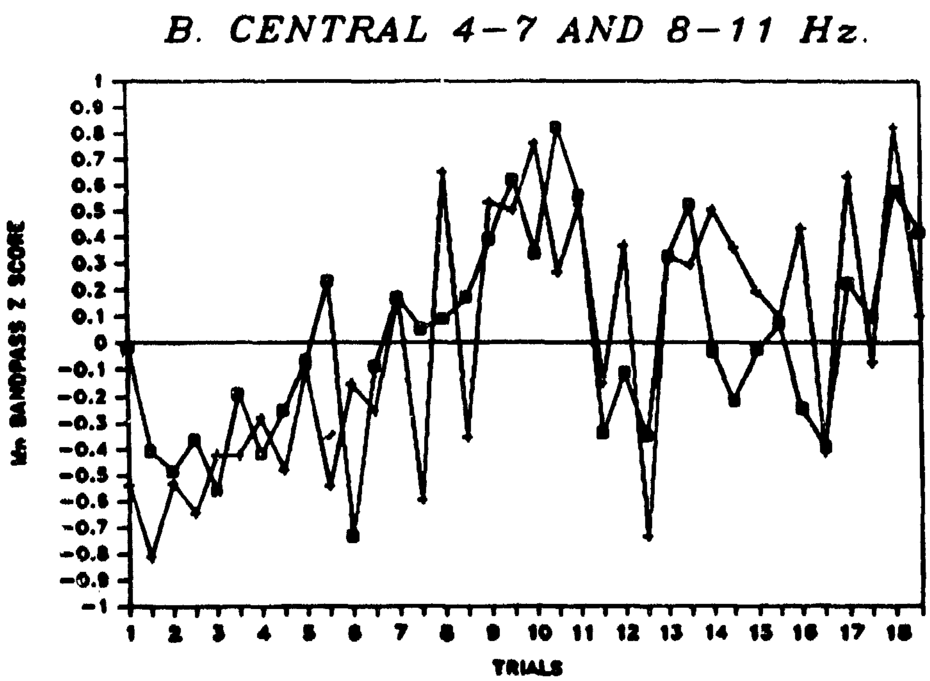


Fig. 1. Mean integrated (15 s) bandpass response (Z-score transform) in two frequency bands from EEG data recorded over two different cortical sites across 18 trials of alternating performance and nonperformance epochs in a visual-motor "flying" task. Data from parietal-occipital cortex (P_3-O_1) at A show decreased density in 4-7 (+) and 8-11 (□) Hz activity during performance epochs (indicated by trial numbers) and increased density during nonperformance epochs (indicated as points between trial numbers). Data from central cortex (C_1-C_5) at B show the opposite pattern but primarily in the 8-11 Hz band (+). At this cortical site, density was increased during performance relative to nonperformance. Periodicity here was imposed by the experimental work schedule.

site, periodicity was clearest in the 8-11 Hz band and this activity was generally enhanced during performance and suppressed in nonperformance epochs. The consistency of this cycling was particularly surprising in view of the variable activity characteristic of nonperformance periods in a group of diverse individuals, and suggests a basic dichotomy between scheduled and nonscheduled activities. The clear reciprocity observed between parietal-occipital and central cortical EEG frequencies indicates that quite different functional activities are occurring in these two cortical areas during performance vs rest periods.

A close examination of this periodicity suggested that the reciprocity in frequency modulation between performance and nonperformance epochs at both cortical sites was not constant. Accordingly, difference scores were calculated for the central 8-11 Hz and parietal-occipital 4-7 Hz bands by subtracting the nonperformance epoch bandpass values from the preceding performance epoch value for each band across trials (Fig. 2). This anlysis disclosed a marked ultradian periodicity in both bands, with an estimated cycle length ranging from 75 to 90 minutes.

In an effort to determine the origins of this slower, intrinsic cycle, a different analysis was explored. In this case, sequential bandpass values from performance and nonperformance epochs were plotted separately across trials (Fig. 3). Considering performance epochs only (3-B), a general trend was observed in all data such that the activity in central cortical EEG frequency bands showed a gradual increment across trials, which leveled off by the middle of the session, while the parietal-occipital frequency bands showed a more

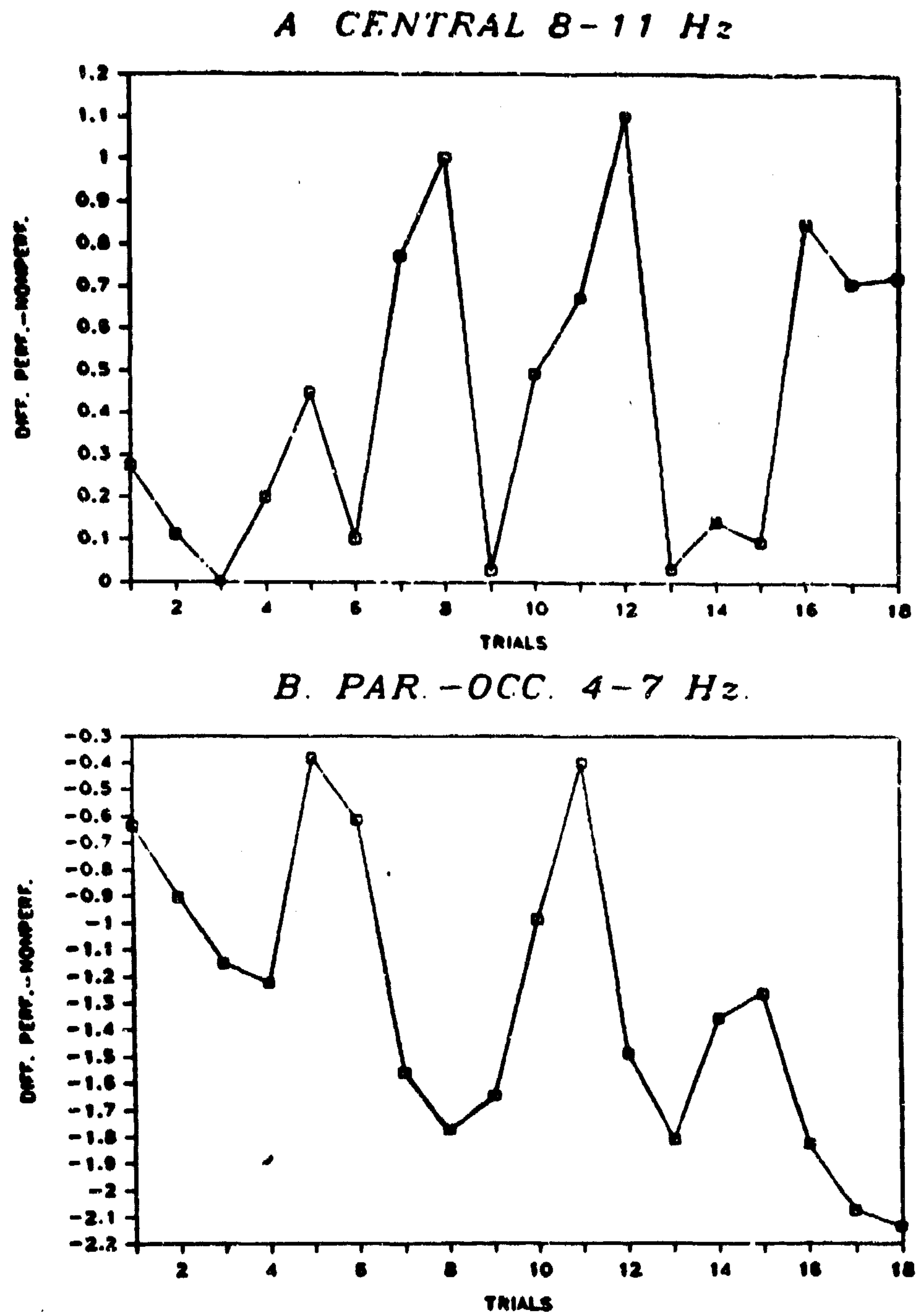


Fig. 2. Plot of successive "difference scores" derived by subtracting bandpass density values obtained during performance epochs from those registered during subsequent non-performance epochs. Scores from central 8-11 Hz data show a marked periodicity ranging from 75 to 90 min, with peak values trending upwards across trials, while those obtained from parietal-occipital 4-7 Hz data suggest a reciprocal periodicity, with troughs trending downwards across trials.

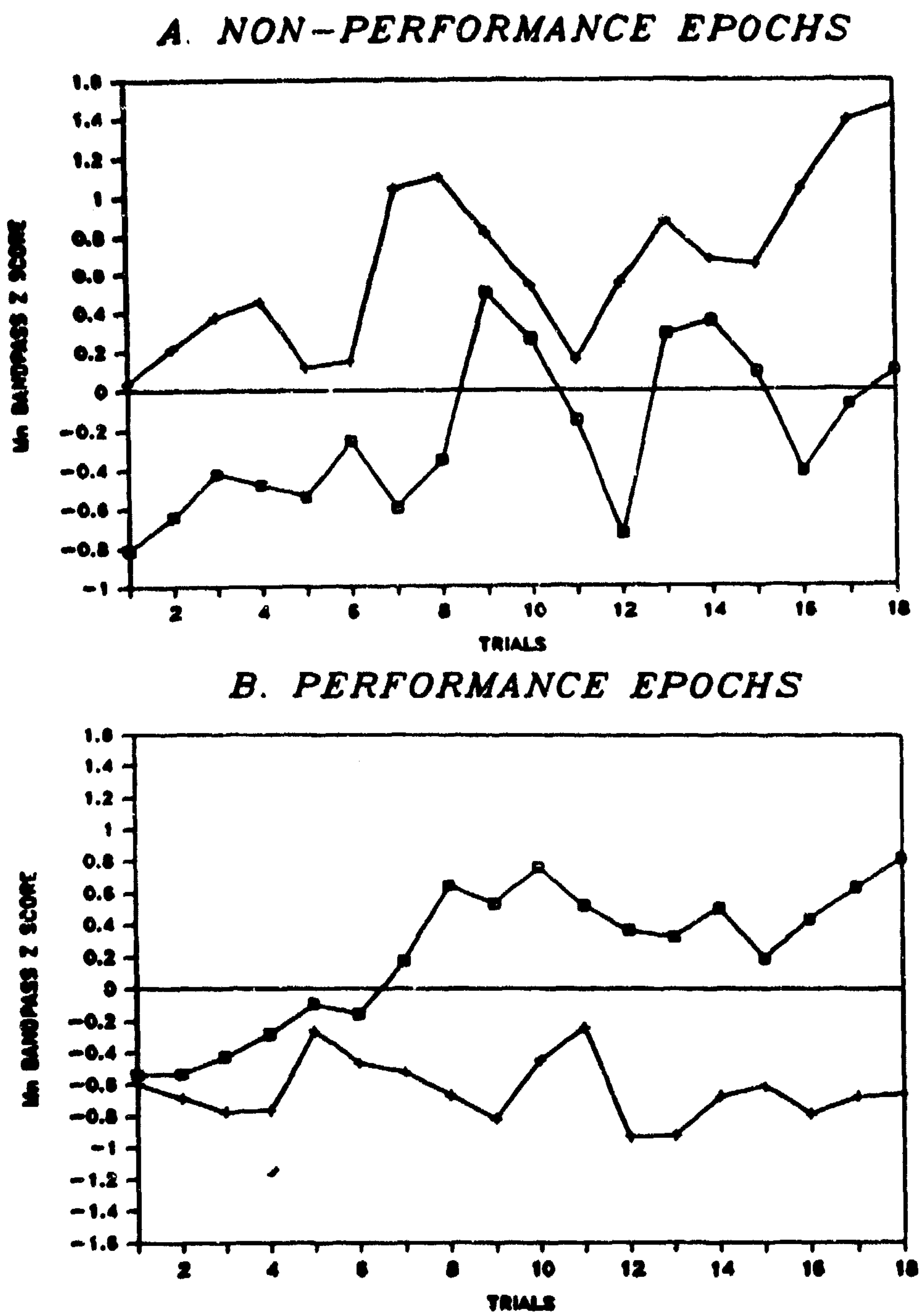


Fig. 3. Sequential bandpass analysis values, as in Fig. 1, separating nonperformance (A) and performance (B) data points for parietal-occipital 4-7 Hz activity (+) and central 8-11 Hz activity (□). Note that performance values show reciprocal and more or less linear trends across trials, with central 8-11 Hz density increasing, while nonperformance values describe a parallel periodicity of 75-90 min. Moreover, nonperformance data indicate a reversal in relative densities since parietal-occipital values are highest.

modest and reciprocal decline. The combined performance measure used in this study also showed an improvement across trials. This trend was very similar to the increment in central cortical 8-11 Hz activity noted across performance epochs. Due to the restricted nature of performance assessment, however, no statistical analysis of this relationship was attempted.

In contrast to the linear character of EEG frequency changes during performance epochs, the pattern during nonperformance epochs was periodic, with an overall higher power apparent in the parietal-occipital data (3-A). This periodicity again showed an estimated cycle range of 75-90 minutes. Moreover, it was manifested in both central 8-11 Hz and parietal-occipital 4-7 Hz activity patterns.

Discussion

A number of conclusions can be drawn from these findings. First, as might be expected, state changes during wakefulness systematically influence physiology, just as they do during sleep. In this case, the state changes were dictated by an experimental task schedule. While this is not a surprising finding, it is indicative of the many influences which can confound the study of biologic periodicity outside of the laboratory. Additionally, when more complex physiologic variables are of interest, such as the EEG in this case, experimentally imposed periodicity can define the limits of response within a given context, aid in selecting appropriate quantitative measures, and provide important clues concerning the functional substrates of the response observed. With regard to the latter, it is apparent from these data that rhythmic EEG

activity in central cortex, resembling the mu (Gastau et al, 1952) and sensorimotor (Sterman et al, 1974) patterns related to movement suppression was specifically enhanced during a finely controlled visual-motor task. Conversely, slower rhythmic activity in the theta range over visual cortical areas was suppressed. This reciprocity was also observed to increase with practice at this task and may correlate with improved performance.

The limited quantification of performance available in this study prevents any firm conclusion regarding EEG correlates of performance variations. We did observe a general trend towards improved performance across trials, and this was paralled by an increment in central cortical 8-11 Hz activity. Interpretation of these findings, however, is confounded by the fact that both learning and fatigue were occurring across trials. Subjects were provided with practice prior to the experimental session but had not achieved documented proficiency. Thus, performance improvement would be expected despite the fact that fatigue was also developing. The observed EEG trend could reflect either process or be modified by their combined influence.

These data again disclosed an intrinsic ultradian periodicity of approximately 90 minutes during prolonged periods of sustained wakefulness. This periodicity was manifested in the modulation of EEG characteristics during recurrent periods of unscheduled activity. It is reasonable to propose that the demand character of the task dominated neural functioning during performance periods and that the resulting cerebral engagement masked underlying functional periodicity. Conversely, during nonperformance periods attention was reduced and this condition provided the most appropriate circumstances for detection of

a rest-activity cycle in this situation. One of our primary objectives in these studies is to identify practical physiologic measures of this modulation. Tracking such measures may provide a basis for anticipating performance decrement and/or sustaining optimal response characteristics.

2. EEG and Neuropsychological Correlates of Flight-Related Performance During Prolonged Simulated Flight.

Introduction

The major limitation of the study described above was the rudimentary quality of performance measurement. Because of a lack of sophisticated simulation equipment, we were forced to limit performance assessment to a composite measure derived from recurrent tests of short term memory with each trial of the study combined with an estimate of the time required to complete the assigned course changes. This measure provided only an approximation of performance since we could not independently confirm the accuracy of instructed course changes. This shortcoming did not, however, interfere with our evaluation of periodicity in EEG frequencies, and the limited performance data obtained provided meaningful clues as to EEG correlates of this task.

In this second study, we attempted to overcome these limitations by developing a greatly improved approach to performance evaluation. Additionally, we added a battery of neurophysiological tests aimed at providing an overall assessment of personality variables in our subjects and a specific, intermittent evaluation of subjective feelings across a demanding flight scenario. The

primary objectives of this study were once again to evaluate EEG characteristics during performance and the effects of fatigue on these measures. Moreover, an appraisal of subjective feelings of fatigue provided an index of perceived state changes, which could be compared with objective EEG data.

Methods

Ten senior Air Force ROTC cadets were recruited from universities in our area to serve as subjects in this study. This group consisted of nine males and one female and ranged in age from 20-24 years. All had solo flight experience in excess of 100 hours. These subjects were in good physical health and demonstrated stable, well-adjusted personalities. Several were already assigned to post-graduate Air Force flight training facilities.

Flight simulation for this study employed the software from "Flight Simulator II," manufactured by Microsoft Corporation for the IBM-PC. This program approximates the instrumentation and flight characteristics of a Cessna 182 class, single engine aircraft. It was chosen because it offered realistic performance features with which most Air Force ROTC cadets would be familiar and, accordingly, would take less training time to fly successfully.

The subjects were isolated and seated comfortably in a cockpit mockup in front of a color video monitor. They were provided with authentic manual control devices for manipulation of air speed (throttle) and altitude and pitch (control yolk). The video screen presented the instrument cluster of the airplane along with the view from the plane's cockpit. In each case, the investi-

gator, seated in an adjacent room, acted as a co-pilot, communicating with the subject via a radio headset. In addition, a video camera monitored the subject throughout the experiment in order to record significant movements and other events which could generate EEG artifact.

Each subject was provided with four one-hour practice sessions to assure familiarity and competence in the actual test situation. They were shown literature explaining the use of the instruments, preflight pilot information for the Microsoft flight program, and other flight-related issues. These information sheets described minor anomalies and unusual characteristics of the simulator, as well as an outline of the procedure. Additionally, subjects were given the following rules of procedure:

1. Restrict use of radar views to ten seconds;
2. Keep facial muscles as relaxed as possible;
3. Follow the protocol for each flight leg as closely as possible; and
4. Keep verbal communication to a minimum.

Criteria used to determine readiness for the experimental trial were:

1. Take off and land successfully anywhere;
2. Take off, turn around and land successfully on the same runway;
3. Take off, fly to another designated airport and land successfully; and
4. Successfully follow a prescribed flight leg as the protocol demands.

Once subjects had demonstrated competency in flying the simulator, they were

scheduled for the prolonged experimental performance session. Each was also required to complete a Minnesota Multiphasic Personality Inventory (MMPI) prior to the experimental trial.

During the actual test trial, subjects were monitored electroencephalographically throughout a session of approximately six hours. Four standard bipolar EEG placements were employed to provide bilateral recording from the somatosensory area (C1-C5, C2-C6) and the occipito-parietal area (01-P3, 02-P4). Gold-plated cup electrodes were fixed to the prepared scalp with collodian adhesive and attached to Oxford Medilog miniature preamplifiers. These leads, together with a neutral ground, were fed to a Grass model "B-16" electroencephalograph and an eight channel Crown Vetter model "A" magnetic tape recorder. Leads from the electroencephalograph also fed EEG data directly into a VAX 11/750 computer system for on-line data collection and EEG power-spectral analysis, utilizing a standardized power spectral program. Successive sixteen-second epochs of EEG data were analyzed for the entire performance session. These data were digitized, subjected to Fast Fourier Transform, scaled and log transformed.

Before the experiment began, each subject completed a battery of neuropsychological tests, including the Stanford Sleepiness Questionnaire, the Profile of Mood States (POMS), the Thayer's Activation/Deactivation Checklist, and the N.I.M.H. Visual Analogue Scale. The latter three tests were repeated during each of seven inter-leg rest periods and after the eighth flight leg. The experimental protocol required the subject to take off from a particular airport, fly to a designated spot, turn to a new heading and land at a desig-

nated airport. Each of these flight legs was designed to be relatively comparable and to be completed within thirty minutes. After each flight leg a twelve-minute rest period was provided, during which the standard rest period battery (POMS, Checklist, NIMH Scale) was completed. Subjects were also given an opportunity to look over the protocol for the next flight leg.

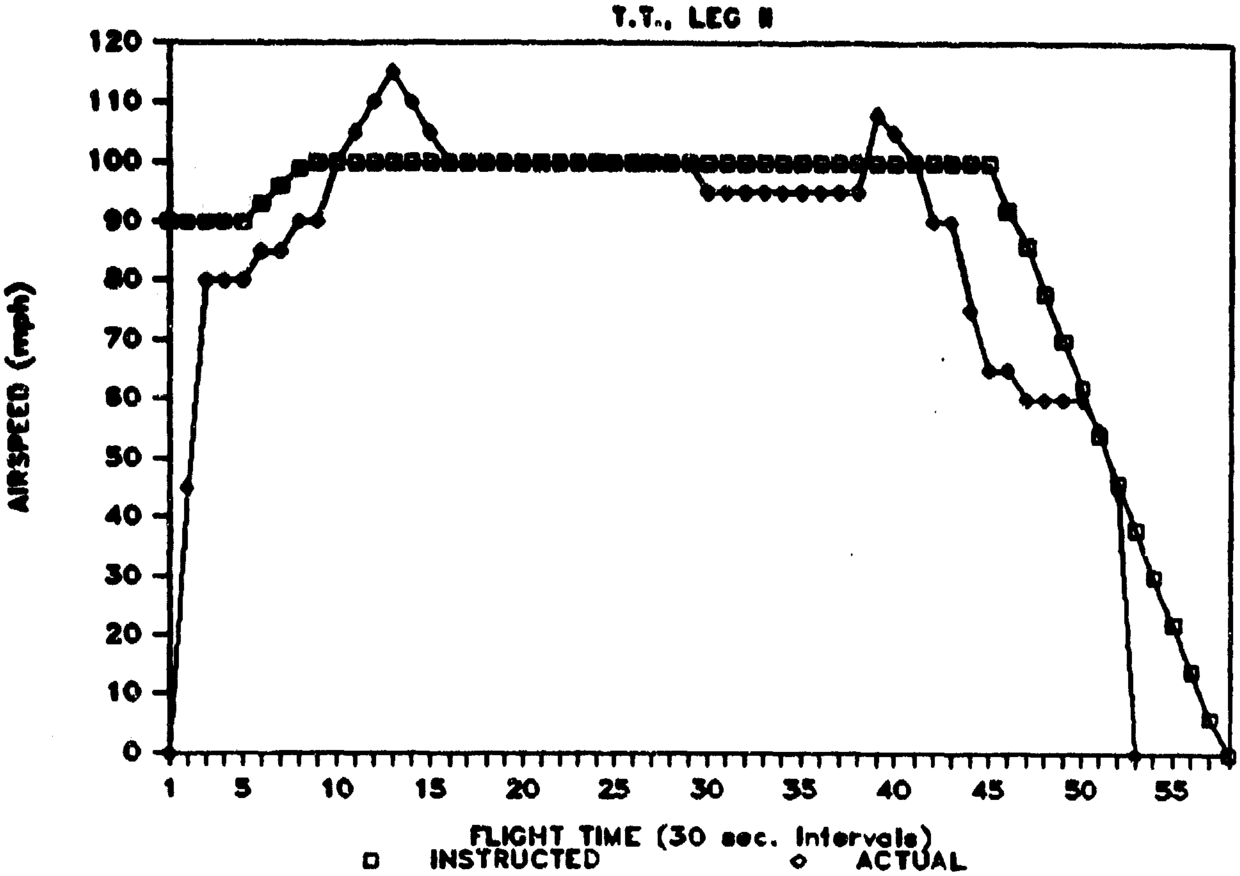
A Mitsubishi Video Printer model "P50-U" produced a hard copy of the video screen every thirty seconds during each flight leg. This printout yielded accurate information concerning position, heading, altitude, air speed, rate of ascent/descent, and position of the throttle and yolk. These data were transcribed manually into a Lotus 123 file and compared with instructed parameters in order to provide a quantatative measure of performance accuracy. Additionally, other characteristics of performance were logged, including appropriate use of landing gear, flaps and essential flight information provided by the co-pilot, as well as the success or failure in landing the aircraft, which was clearly the most difficult aspect of the task.

Preliminary Results

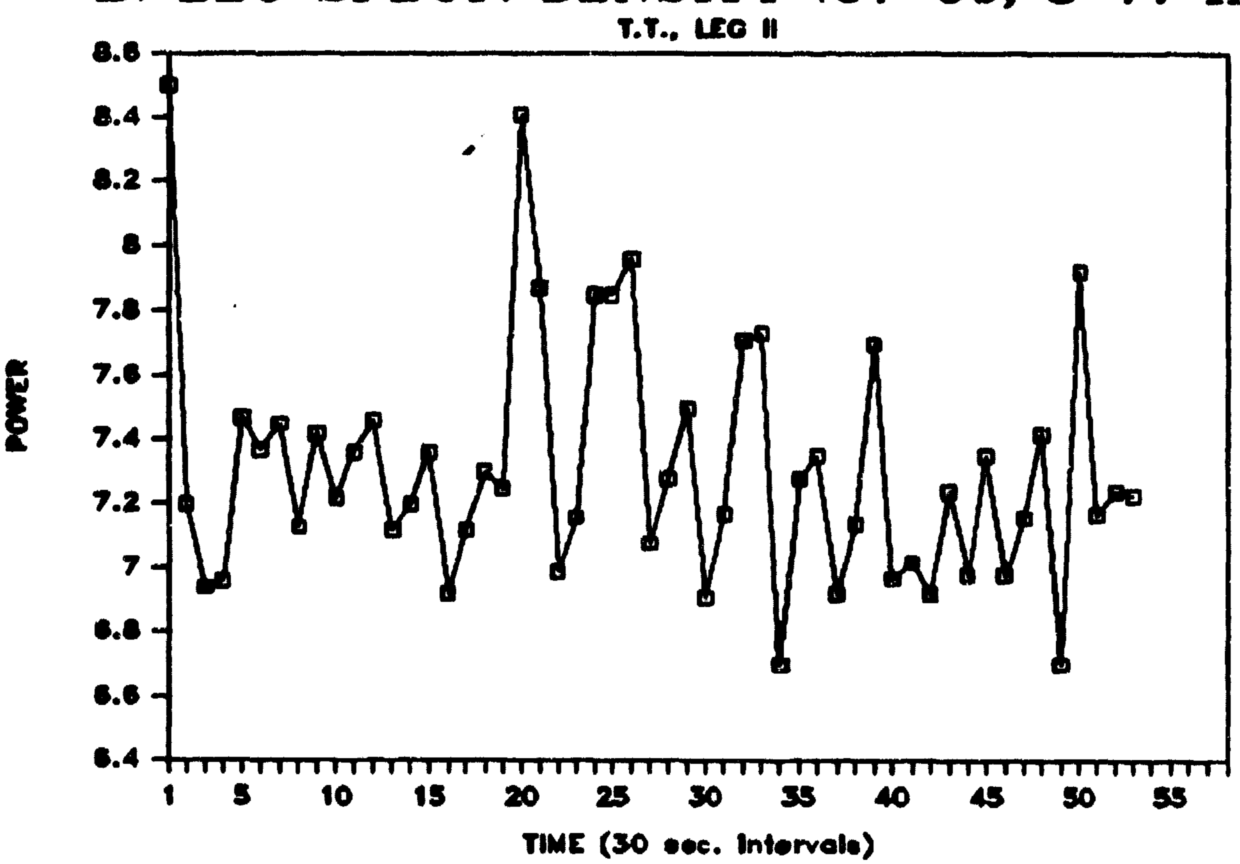
The enormous quantity of EEG and performance data generated by this study is currently being analyzed by our staff. At present, it is possible only to describe preliminary findings. These, however, demonstrate clearly the potential wealth of information that this study should provide.

Figure 4-A shows a plot of airspeed control during the second leg of the flight scenario from one subject. This is compared with the instructed airspeed

A) AIRSPEED CONTROL: INSTRUCT. vs PERF.



B) EEG SPECT. DENSITY (C1–C5, 8–11 Hz)



characteristics during this leg. The subject was directly requested to achieve an airspeed of 90 knots at takeoff and then to accelerate to 100 knots at a specific time shortly afterwards. This speed was to be maintained throughout the "enroute" phase of the flight and then reduced with the onset of the landing phase and decreased gradually until the plane was landed. This instructed format is shown by the curve defined by open squares in Figure 1. Actual performance is indicated by the curve defined by diamonds. As in most legs, the pilot tended initially to overshoot the required enroute airspeed. However, his accuracy in following instructions during this leg was very high.

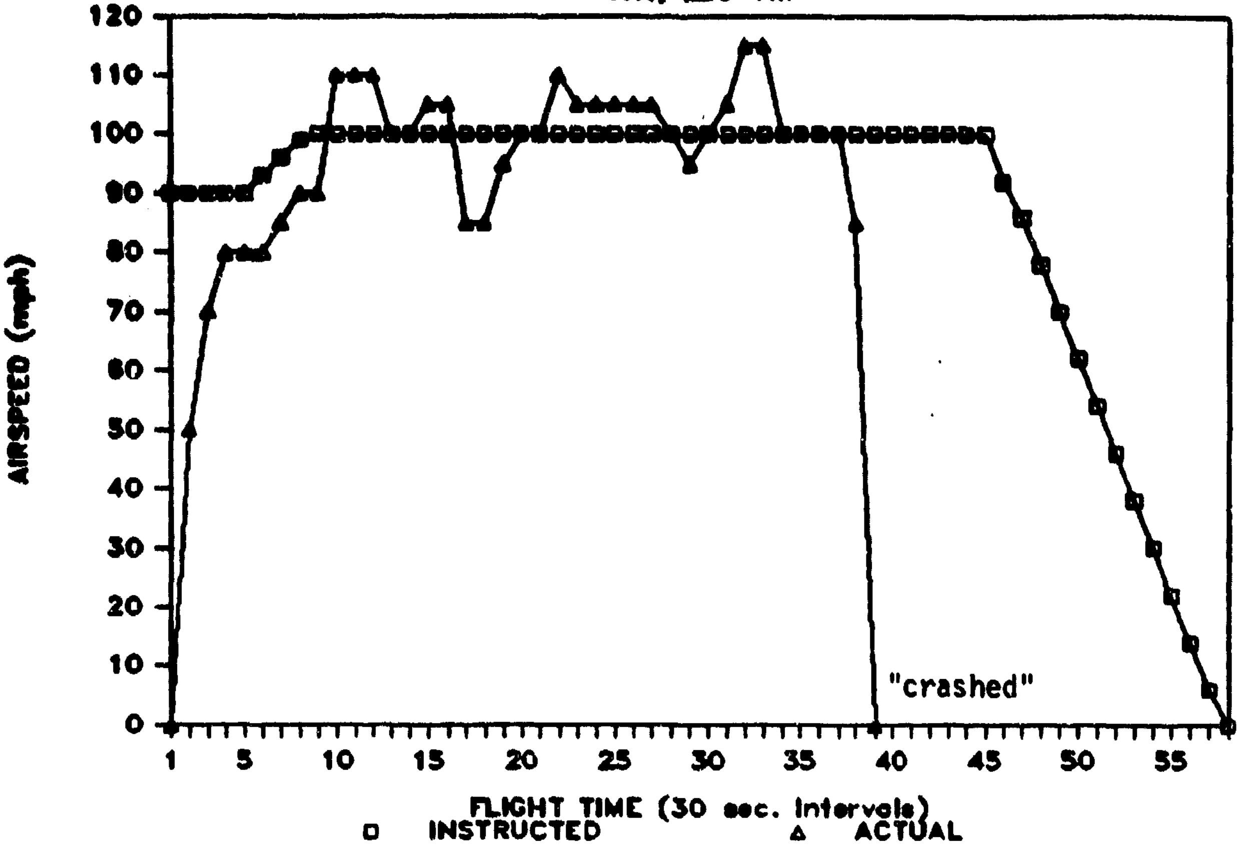
Corresponding EEG spectral activity for the 8-11 Hz band from the left central cortical area is shown at B in Figure 4. A clear periodicity was apparent at this frequency and this periodicity changed during the different phases of the flight scenario. Thus, a relatively stable 1-2 minute cycle was present during takeoff and course adjustment and appeared again at the beginning of landing maneuvers. During the bulk of the "enroute" phase, this was replaced by a slightly slower and clearly increased modulation of power at this frequency.

Figure 5 shows similar data from leg eight of the flight test. Airspeed control, shown again at A, required the same adjustments as in leg two. On this leg, however, the subject had great difficulty maintaining stable performance and actually "crashed" the aircraft at the beginning of the landing phase. Corresponding EEG data, shown at B, indicate that significant changes in EEG modulation paralleled this failure in performance. Overall power in the central cortical 8-11 Hz band was elevated, as was the amplitude of cycle modulation throughout the flight. The changes associated with the enroute phase were

Fig. 4. Performance in controlling aircraft velocity according to instructions is shown here in one subject during the second leg of the simulated flight scenario, together with corresponding EEG power spectral density in the 8-11 Hz band from central cortex. Performance, shown at A as curve defined by diamonds, is compared with the instructed airspeed parameters, shown in the curve defined by squares. The subject landed the aircraft successfully after 26.5 min of flying. EEG spectral analysis, shown at B, indicated an intrinsic 1-2 min periodicity which changed in characteristics during the "straight and level" or "enroute" phase of the flight.

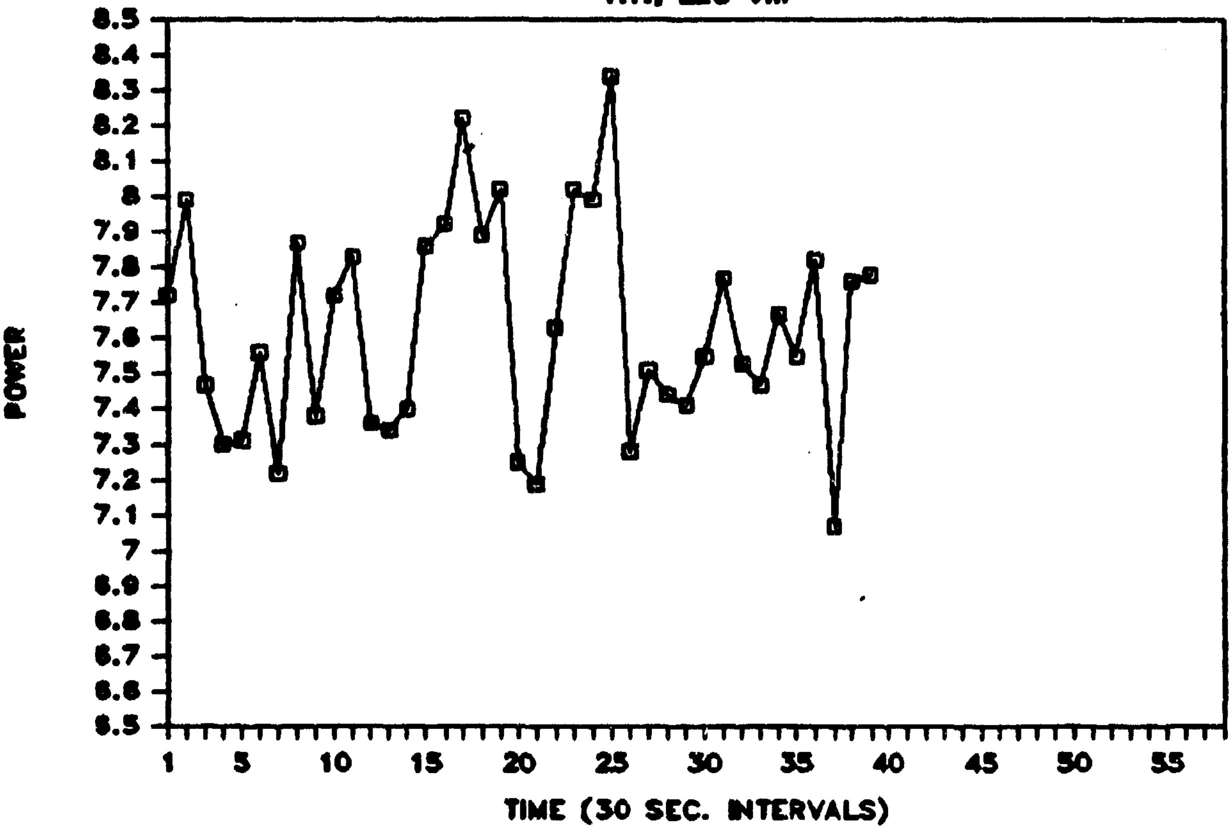
A) AIRSPEED CONTROL: INSTRUCT. vs PERF.

T.T., LEG VIII



B) EEG SPECT. DENSITY (C1–C5, 8–11 Hz)

T.T., LEG VIII



exaggerated, with increased power and greater slowing.

These findings, if they are confirmed with other performance measures and are consistent across subjects, suggest that the dynamics of sensorimotor cortical EEG activity during flight performance may, indeed, provide a marker as to functional capability changes. The central, or sensorimotor cortical area, has important frequency components which previous work has shown to reflect cerebral excitability. These data suggest that power in the 8-11 Hz band over the dominant hemisphere may label the dimension of "effort" in sensorimotor performance tasks. Such a conclusion would be consistent with previous findings and, together with an expanded perspective which the completed analysis of data collected in this study should provide, may aid us significantly in our effort to further define and utilize cortical EEG signals in support of pilot performance.

3. In-flight monitoring of central nervous system.

Introduction

The objectives of this work, which was also supported under Air Force Flight Test Center Job Order #A85005, Edwards Air Force Base, was to perfect techniques and equipment for measuring and evaluating brain electrical patterns associated with the continuum of consciousness spanning the limits from hyperarousal to black out. Current aircraft and mission characteristics require sustained, high levels of pilot performance which can exceed pilot capability. Factors responsible for this problem include situational confusion, workload, fatigue and

Fig. 5. Comparison of airspeed-control performance and central cortical 8-11 Hz spectral density as in Fig. 4 but from the eighth and final leg of the flight scenario. Instructed airspeed parameters were identical to those used in leg two. Note the instability of airspeed control and the altered characteristics of corresponding central 8-11 Hz EEG activity. The subject lost control of the aircraft during preparation for landing and "crashed" at a point approximately 20 min into the flight.

G-induced changes in consciousness. Since the status of central nervous system function is critical to both optimal and failed performance, it was felt that the direct measurement and decoding of CNS electrical activity would provide the most meaningful approach to the monitoring and support of in-flight capabilities. This conclusion is consistent with the laboratory findings described above. Our specific aim in this work is to develop a feasible monitoring technology and appropriate signal evaluation capability so as to provide for a routine, non-invasive methodology for recording and utilizing brain electrical activity in support of flight-related performance.

Methods

Working in close collaboration with the Life Support, Aerospace Medicine and Test Operations branches at the Air Force Flight Test Center, we have perfected an interim version of a flight helmet with built-in EEG detection capability. This helmet consists of a removable inner layer, molded to the subject's head. It is perforated by seven channels for the insertion of stylus-type electrode rods containing gold-plated Grass electrode cups covered by special foam contacts. The channels correspond to EEG placements C1-C5, C2-C6 and P3-01, according to the International 10-20 System, as well as a frontal ground. Prior to insertion of the electrode rods, the scalp at the specific site of contact is briefly cleansed, abraded and covered with a conductive paste. The electrode is then inserted, checked for resistance, and attached to a miniature pre-amplifier imbedded in the inner helmet. Bipolar electrode pairs are attached to these pre-amplifiers and all wire leads, which are also imbedded, brought out at the rear of the inner layer. These are then fed down the back of the subject's

flight suit and out of a velcro-sealed opening under the right arm. The outer layer of the helmet is then placed over this configuration and the two units held together by velcro strips. The chin strap then secures the entire helmet to the pilot's head. Connectors at the end of the lead wires are attached to a small power supply box fixed to the parachute strap on the right side of the chest. Additionally, a parallel connector from the helmet intercom cable is attached to this box.

A single cable from the power supply unit is then led to a receptacle in the life-support kit under the pilot's seat. This contact connects the entire system to a miniature 4 channel amplifier and micro analog tape recorder system packed with protective foam into the life-support kit. All contacts are of the "snap-release" type and pose no impediment to pilot ejection. The resulting configuration provides for the continuous recording of three bipolar EEG signals and a voice channel chronicle of in-flight events.

Following the flight, usually lasting 60-80 minutes, the tape cartridge is removed from the recorder and returned to our laboratory for transcription to polygraphic and laboratory magnetic tape mediums. The time-locked voice record of in-flight events is transcribed onto the polygraphic record and converted to an event code. The re-recorded EEG signals are then subjected to Fast Fourier Transform using an algorithm of Jennrich (1970) in a program of Pacheco et al., 1974). Successive 16 sec samples (2048 data points) are analyzed, with 128 coefficients summed to provide a resolution of 0.5 Hz from 0 to 40 Hz. To correct for differences in scaling, spectra of a standard 50 uV, 13 Hz sine wave recorded at the beginning of each flight are calculated also, and the EEG spectra

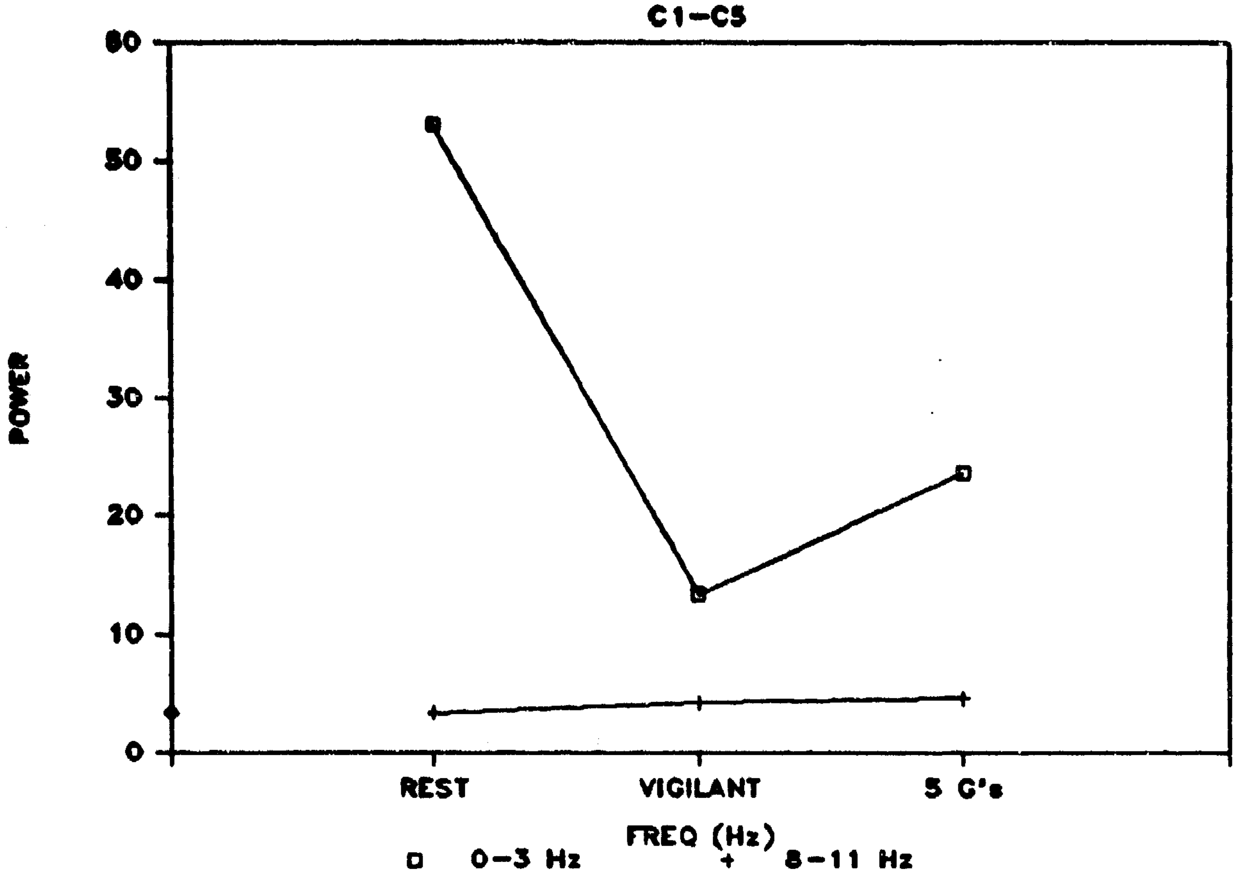
scaled by reference to a ratio of the calibration peak to an arbitrary amplitude. Equated spectra are scanned visually to remove values produced by confirmed movement artifact. Values are sorted into six 4 Hz frequency bands between 0 and 23 Hz (i.e., 0-3, 4-7, 8-11, 12-15, 16-19 and 20-23 Hz). Spectral density in each of these bands is computed by calculating the area under the spectral curve during each successive 16 sec epoch over the sample period. Sample means are computed for spectral density in each band and these values subjected to log transformation.

Results

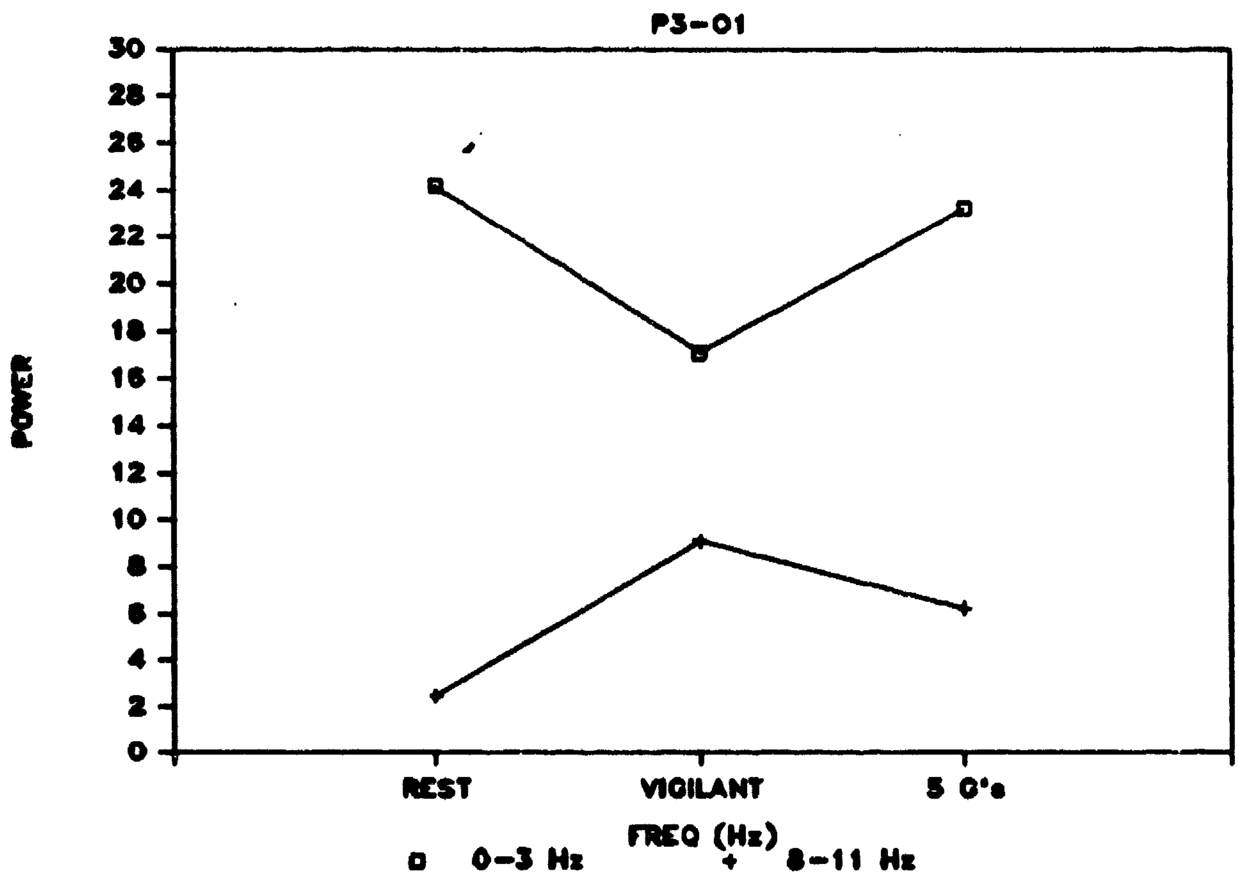
Data from five successful recording flights have been evaluated. While data analysis is still underway, a number of preliminary conclusions are possible. Figure 6 shows data from a representative recording which focuses on spectral changes in several important frequency bands from the left central cortical signal and compares spectral density distributions in three conditions. In this and other brain areas the lowest frequencies were markedly attenuated with the transition from quiet, straight and level flight to preparation for active maneuvers. During sustained high G force the opposite response was obtained. That is, power in the lowest frequencies was increased. Similar data obtained from the parietal-occipital area were even more interesting. Here, density in the 0-3 Hz band again decreased with increased vigilance, as in central cortex, but activity in the adjacent 4-7 and 8-11 Hz bands showed a unique increase. Under conditions of high G force this more complex pattern again reversed, with low

Fig. 6. Power spectral analysis of EEG activity in two frequency bands (0-3 Hz and 8-11 Hz) at two cortical sites (central and parietal-occipital) is shown here from a passenger in a T-38 aircraft during different conditions in a training flight. Mean spectral densities from one minute samples were calculated during rest with eyes open, high vigilance in normal flight, and periods of sustained 5 G-force stress. Note that 0-3 Hz activity in both cortical areas was attenuated with the onset of vigilance (instructed instrument scanning) but increased again during high G-force-conditions with visual scanning. Activity in the 8-11 Hz band increased during visual scanning in the parietal-occipital area but was again attenuated with the addition of high G-force.

EEG SPECTRAL PROFILES: REST–VIG.–G's



EEG SPECTRAL PROFILES: REST–VIG.–G's



frequency activity increasing to resting levels and higher frequency patterns decreased to intermediate values.

Discussion

These data, while preliminary, demonstrate encouraging dynamics in the EEG accompanying different behavioral states. It should be remembered that the subject from whom these data were collected was a passenger in the aircraft and was not actually responsible for the events being imposed. Moreover, it is important to note that the physical restraint and intense environment associated with flight in fighter aircraft produce uniquely activated physiological response patterns. Despite these facts, and with a signal that is inherently low in voltage, we were able to obtain viable data suggesting both generalized and specific changes in brain functions associated with differing physiological conditions. The transition from routine to more vigilent flight activity was accompanied by a marked and generalized decrease in low frequency activity and a specific increase in intermediate frequency bands over visual-perceptual areas of cortex. These dynamics suggest an adaptive mobilization of pathways involved in visual-motor attention and signal processing, as might be expected. The reversal of both of these patterns under high G-force conditions therefore implies a reduction in visual-motor response capabilities and could represent a transition point towards loss of consciousness. We intend to explore these possibilities further through continued improvement in data collection methods and an expanded evaluation of workload and G-force correlations.

Publications

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Presentations

Sterman, M.B., Hamel, A.S. and Dushenko, T. EEG correlates of flight-related sensory-motor performance. Symposium of applications of biofeedback in aerospace physiology. Biofeedback Soc. of Calif., annual meetings, Monterey, CA, Nov., 1984.

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characteristics during this leg. The subject was directly requested to achieve an airspeed of 90 knots at takeoff and then to accelerate to 100 knots at a specific time shortly afterwards. This speed was to be maintained throughout the "enroute" phase of the flight and then reduced with the onset of the landing phase and decreased gradually until the plane was landed. This instructed format is shown by the curve defined by open squares in Figure 1. Actual performance is indicated by the curve defined by diamonds. As in most legs, the pilot tended initially to overshoot the required enroute airspeed. However, his accuracy in following instructions during this leg was very high.

Corresponding EEG spectral activity for the 8-11 Hz band from the left central cortical area is shown at B in Figure 4. A clear periodicity was apparent at this frequency and this periodicity changed during the different phases of the flight scenario. Thus, a relatively stable 1-2 minute cycle was present during takeoff and course adjustment and appeared again at the beginning of landing maneuvers. During the bulk of the "enroute" phase, this was replaced by a slightly slower and clearly increased modulation of power at this frequency.

Figure 5 shows similar data from leg eight of the flight test. Airspeed control, shown again at A, required the same adjustments as in leg two. On this leg, however, the subject had great difficulty maintaining stable performance and actually "crashed" the aircraft at the beginning of the landing phase. Corresponding EEG data, shown at B, indicate that significant changes in EEG modulation paralleled this failure in performance. Overall power in the central cortical 8-11 Hz band was elevated, as was the amplitude of cycle modulation throughout the flight. The changes associated with the enroute phase were

Fig. 4. Performance in controlling aircraft velocity according to instructions is shown here in one subject during the second leg of the simulated flight scenario, together with corresponding EEG power spectral density in the 8-11 Hz band from central cortex. Performance, shown at A as curve defined by diamonds, is compared with the instructed airspeed parameters, shown in the curve defined by squares. The subject landed the aircraft successfully after 26.5 min of flying. EEG spectral analysis, shown at B, indicated an intrinsic 1-2 min periodicity which changed in characteristics during the "straight and level" or "enroute" phase of the flight.

exaggerated, with increased power and greater slowing.

These findings, if they are confirmed with other performance measures and are consistent across subjects, suggest that the dynamics of sensorimotor cortical EEG activity during flight performance may, indeed, provide a marker as to functional capability changes. The central, or sensorimotor cortical area, has important frequency components which previous work has shown to reflect cerebral excitability. These data suggest that power in the 8-11 Hz band over the dominant hemisphere may label the dimension of "effort" in sensorimotor performance tasks. Such a conclusion would be consistent with previous findings and, together with an expanded perspective which the completed analysis of data collected in this study should provide, may aid us significantly in our effort to further define and utilize cortical EEG signals in support of pilot performance.

3. In-flight monitoring of central nervous system.

Introduction

The objectives of this work, which was also supported under Air Force Flight Test Center Job Order #A85005, Edwards Air Force Base, was to perfect techniques and equipment for measuring and evaluating brain electrical patterns associated with the continuum of consciousness spanning the limits from hyperarousal to black out. Current aircraft and mission characteristics require sustained, high levels of pilot performance which can exceed pilot capability. Factors responsible for this problem include situational confusion, workload, fatigue and

Fig. 5. Comparison of airspeed-control performance and central cortical 8-11 Hz spectral density as in Fig. 4 but from the eighth and final leg of the flight scenario. Instructed airspeed parameters were identical to those used in leg two. Note the instability of airspeed control and the altered characteristics of corresponding central 8-11 Hz EEG activity. The subject lost control of the aircraft during preparation for landing and "crashed" at a point approximately 20 min into the flight.